

Final R -value results from 2-5 GeV from BES and QCD test with R scan data

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Final results of the measurement of $R = \sigma(e^+e^- \rightarrow \text{hadrons})/\sigma(e^+e^- \rightarrow \mu^+\mu^-)$ in the energy region from 2 to 5 GeV with the upgraded Beijing Spectrometer (BESII) at the Beijing Electron Positron Collider (BEPC) are presented. Preliminary results of the inclusive momentum spectra and second binomial moment measured with the R scan data at 2.2, 2.6, 3.0, 3.2, 4.6 and 4.8 GeV are reported.

1. Introduction

The lowest order cross section for $e^+e^- \rightarrow \gamma^* \rightarrow \text{hadrons}$ in units of the lowest-order QED cross section for $e^+e^- \rightarrow \mu^+\mu^-$ is defined as R , namely $R = \sigma(e^+e^- \rightarrow \text{hadrons})/\sigma(e^+e^- \rightarrow \mu^+\mu^-)$, where $\sigma(e^+e^- \rightarrow \mu^+\mu^-) = \sigma_{\mu\mu}^0 = 4\pi\alpha^2(0)/3s$. Presently the uncertainty in R in the energy region below 5 GeV dominates the uncertainties in both $\alpha(M_Z^2)$, the QED running coupling constant evaluated at the Z pole, and a_μ^{SM} , the value of $(g-2)_\mu$ based on the Standard Model calculation [1].

Hadron production from e^+e^- annihilation is one of the most valuable testing grounds for Quantum Chromodynamics (QCD). Particularly, it is interesting and important to analyze low energy e^+e^- collision data, for example, the inclusive momentum spectrum, defined as $\xi = -\ln(2p/\sqrt{s})$, where p and \sqrt{s} are the momentum of the charged particles and center-of-mass (c.m.) energy respectively, with today's knowledge. A purely analytical approach giving quantitative predictions for ξ is the QCD calculation using the so-called Modified Leading Logarithmic Approximation (MLLA) [2] under the assumption of Local Parton Hadron Duality (LPHD) [3], which expresses the limiting spectrum for hadrons as

$$\frac{1}{\sigma_{had}} \frac{d\sigma}{d\xi} = K_{LPHD} \times f_{MLLA}(\xi, \Lambda_{eff}) \quad (1)$$

where K_{LPHD} is an overall normalization factor describing hadronization and f is a complex function of ξ and effective scale parameter Λ_{eff} [2]. Eq. 1. is valid in the range of $0 \leq \xi \leq \ln(0.5\sqrt{s}/\Lambda_{eff})$.

Another example is the second binomial moments, which is a measure of the strength of hadron-hadron correlations and a sensitive probe for higher order QCD or non-perturbative effect. It is defined as $R_2 = \langle n_{ch}(n_{ch} - 1) \rangle / \langle n_{ch} \rangle^2$, where n_{ch} is the charged particle multiplicity. According to the next leading order QCD calculation (NLO), R_2 is given by

$$R_2 = \frac{11}{8}(1 - c\sqrt{\alpha_s(\sqrt{s})}) \quad (2)$$

with $c = 0.55(0.56)$ for five (three) active flavors. There has been a long standing discrepancy between the value of R_2 calculated by NLO and that measured with e^+e^- , μ^+p and $\nu_\mu p$ experiments. In addition, there is relatively little data in the energy region below 5 GeV to compare with QCD calculations.

This paper presents the final results of the R values measured with BESII [4] at BEPC in the

energy region from 2-5 GeV. We also report preliminary results on the inclusive momentum spectra, the momentum distribution of charged particles, and second binomial moments R_2 obtained from the analysis of R scan data.

2. R values in 2-5 GeV

Refs. [5,6] describe in detail the R scan performed by BES at 91 energy points between 2-5 GeV, and the experimental study of the background, particularly the beam associated background. The triggers and the determination of the trigger efficiency; the measurement of luminosity; the hadronic event selection and background subtraction; the determination of the detection efficiency for hadronic events; and the initial state radiative correction can be also found in Refs. [5,6].

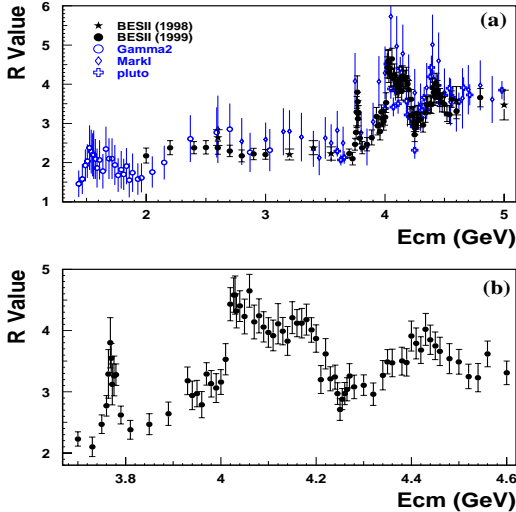


Figure 1. (a) A compilation of measurements of R in the cm energy range from 1.4 to 5 GeV. (b) R values from this experiment in the resonance region between 3.75 and 4.6 GeV.

The final R values measured by BES in this experiment are displayed in Fig. 1, together with those measured by MarkI [7], $\gamma\gamma 2$ [8] and Pluto [9]. The R values from BESII have an average uncertainty of about 6.6%, which represents

a factor of two to three improvement in precision in the 2 to 5 GeV energy region. These improved measurements have a significant impact on the global fit to the electroweak data and the determination of the SM prediction for the mass of the Higgs particle [10]. In addition, they are expected to provide an improvement in the precision of the calculated value of a_μ^{SM} , and test the QCD sum rules down to 2 GeV [11–13].

3. Test of QCD models with R scan data

3.1. ξ spectrum

The measured ξ spectrum at five different energies between 2.6 and 4.8 GeV are shown in Figure 2. The errors in the spectrum include errors from hadronic event selection and uncertainties from the event generators.

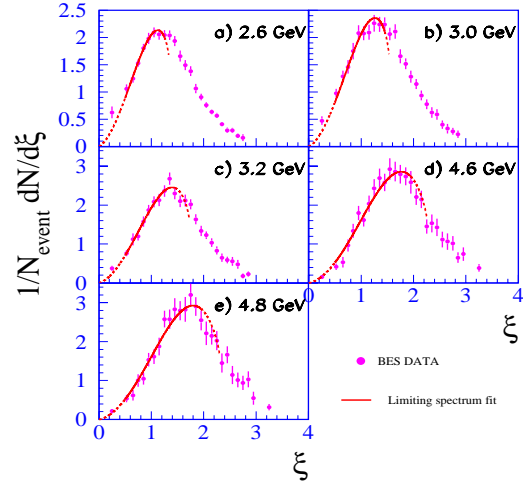


Figure 2. Measured ξ spectrum (solid dot) at 2.6, 3.0, 3.2, 4.6 and 4.8 GeV. Solid curves are the fitting of the limiting spectrum. The dotted line is an extrapolation of the fitted result.

3.2. Momentum spectrum

The momentum spectra at the five energy points are shown in Figure 3, together with those measured at higher energy up to 130 GeV in other experiments. The momentum spectra show that hadron production at very small momen-

tum $p \leq 0.1$ GeV is approximately energy independent. This behavior has been explained in Ref. [14] to be due to the coherent emission of low energetic (i. e. long wavelength) gluons by the total color current. Correspondingly the number of produced hadrons at small momentum is approximately constant.

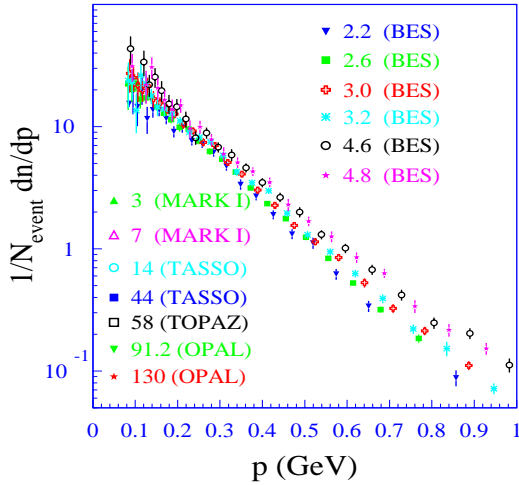


Figure 3. Charged particle momentum spectrum

3.3. Second binomial moment

Based on the multiplicity measured, we can obtain the second binomial moment R_2 . The results are displayed in Figure 4, together with both NLO calculations and published data at higher energies up to 100 GeV from e^+e^- , μ^+p and $\nu_\mu p$ experiments [15,16]. Our measured R_2 , although with large errors, are consistent with those of other measurements done at higher energies.

It's interesting to see that R_2 predicted by LO QCD are significantly higher than the measured data, while the NLO calculation comes closer to the data, although disagreement (~ 0.07 in R_2) remains sizeable.

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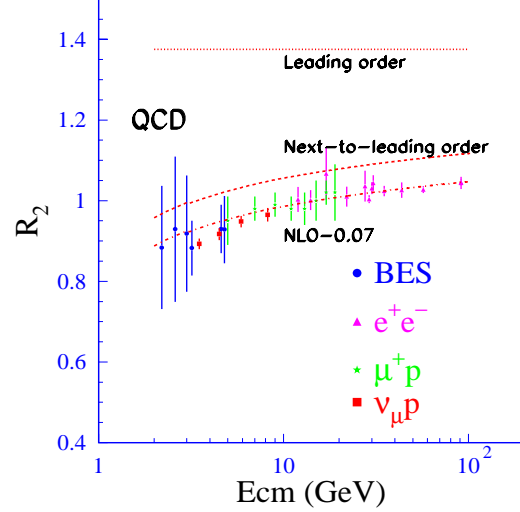


Figure 4. Energy dependence of second binomial moments R_2

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